Comparison of Topology Optimization Techniques for Beam and Ring Type Structures

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ABSTRACT

The paper presents different computational models of beam and ring type structures for the topology optimization having linearly isotropic material. In this paper, different problems have been solved by using ANSYS based optimality criterion approach method. The optimality criterion approach method uses given percentage of volume fraction to minimize the objective function. In this work, the minimum compliance and optimal shape of the structures were optimized. Finally the results have been validate with the results of those different method used by different author for the same material and problem.

Keywords — ANSYS, Topology Optimization, OC Approach, Compliance.

1. INTRODUCTION

In the present scenario, the topological optimization is widely used tool which gives best structural layout at the conceptual level. In topology optimization the optimal layouts are generated automatically to solve the design problems in the field of engineering. The formulation of problem shows the best distribution of material that minimizes objective function with given constraint value. The applications of topology optimization are in many fields such as solid mechanics, fluid mechanics problem, electro mechanics problem, structural problem etc. The use of topology optimization is increasing day by day because it can easily solve typical problems.

There are many topological optimization methods have been developed some of which are homogenization method, evolutionary structural optimization (ESO) method, solid isotropic method with penalization (SIMP) and other methods. In topology optimization there are mainly two types of regions, one is solid other is void. Solid region means the region with material and the void region means the region without material. Topology optimization gives the best suitable use of material over the structure or body such that an objective function (i.e. is to be maximized or minimized) subjected to given constraint should be satisfied.

In the topology optimization, there are two widely used approaches which are based on material distribution model, namely, homogenization method and SIMP method. The SIMP method is easy to implement and has clean concept that is why accepted by many optimization researchers. It also applied in many of the industrial application and also in multiple material phases etc. In design problem, SIMP method is penalization scheme which involve continuous density variables.

Bendsoe et al. [1] started development of topology optimization. They proposed a homogenization method for topology optimization. They assumed that the structure is made by a set of non-homogeneous element which consists of solid and void regions. They obtain optimal design of structure under volume constraint with the help of optimization process. Suzuki et al. [2] studied the shape and topology optimization of linearly elastic material. Author done some modifications in the homogenization method and also clarified the strength of the present approach for plane structure. Michael Yu Wang et al.[3] discussed the structural shape and topology optimization of a linearly elastic structures based on level set models. The author also developed numerical method by using level set model. This is boundary based method and uses implicit, moving boundaries for topology optimization. Author concluded that the shape and topology of structure may undergo major changes. Zhan Kang et al.[7] proposed a nodal design variable based topology optimization which is based on element independent interpolation. By using Shepard interpolants the author constructed the material density field from the design variables points and these design variable points located within the certain influence domain of each computational points. Luo et al. [6] suggested a fuzzy tolerance multiple programming technique for the solution of multi-objective design problem. In this, firstly the single objective problem is classified into groups to find out the optimal solution to their priority and then fuzzy problem is divided into sub-optimization problem and as a result minimized or maximized compliance is obtained. Author also describe about checkerboard and mesh dependencies. Wang et al.[10] proposed an adaptive refinement approach for topology optimization, in which author refines the analysis mesh at different level and find the optimum value of compliance. The author used two indicators, namely, energy error indicator and the gray transitional region indicator for the measurement of analysis accuracy and boundary description. The author concludes that the refinement improves the computational accuracy. Wang et al.[9] focused on adaptive density point refinement approach for topology optimization of structure at reasonable cost. The mesh which is generated by finite element is kept constant during the process of refinement. This approach produces structural boundaries clear and smooth in the final design.

In the present work, the topology optimization of the beam and ring type structure have been done with the help of ANSYS based OC approach method. The minimum compliance and the optimal shape of the structure were optimized. The obtained results have been compared with the same results obtained by different methods used by different authors.

2. PROCEDURE AND TECHNIQUE

Topology optimization problem basically deals with the structural design problem at the concept stage. Topology deals with the optimum distribution of material with specified volume fraction in a selected design domain. The model which is to be optimized, needs to imposed of suitable boundary conditions and applied loads or the model which is to be optimized, required to define with need and specified boundary conditions and loads applied. Compliance is defined as the form of work done. Minimum compliance means the minimum work is done by the load on the body so that the lesser strain energy store in the body which shows that the body is stiff.

In this work, a commercially available finite element solver ANSYS has been used to determine the optimal topology of the structures. In this work, minimization of the compliance has been considered. Mathematically,

$$\text{Compliance} = \int_V fu\, dV + \int_S tu\, dS + \sum_i^n F_i u_i$$

Where,

u = Displacement field

f = Distributed body force (gravity load etc.)

Fi = Point load on ith node

ui = ith displacement degree of freedom

t = Traction force

S = Surface area of the continuum

V = Volume of the continuum

This work has been done on commercially available finite element solver ANSYS which determine the optimal topology of the structure.

3. STRUCTURES DESCRIPTION AND BOUNDARY CONDITIONS

Three structures have been taken in this paper for the validation of results. The structures taken here are having different material properties and different boundary conditions. All the three structures were optimized by ANSYS based OC approach method and then the optimal topology and compliance value is compared by those of different methods.

3.1. Model 1

In this case, a simply supported beam (MBB) of dimensions 120 mm x 20 mm which is loaded at middle is considered. In this case, Young’s modulus is 100, Poisson’s ratio is 0.3 and load applied is 1N has been taken. The given figure1 shows the structure with loading and boundary condition. Table1.1 gives the comparison of compliance value between ANSYS based OC approach method and Adaptive method. The mesh size used is 61, 21 and the volume fraction used is 50%.

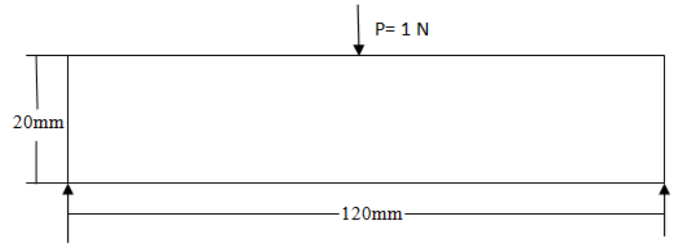
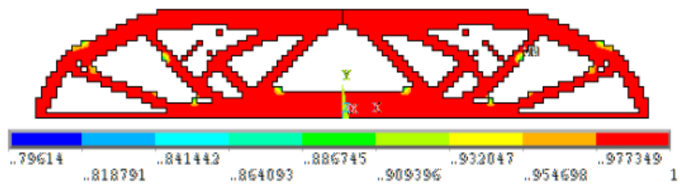


Figure1. Optimized structure of MBB

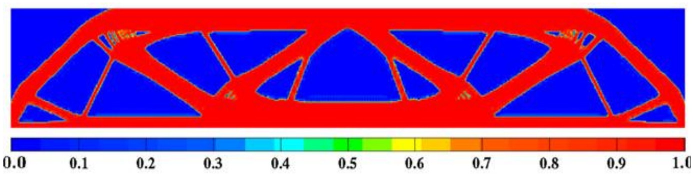
Table 1.1: Comparison between OC and Adaptive method

(n_x, n_y, V_0)	(61, 21, 0.5)	
Method	**ANSYS based OC**	**Adaptive method**
Compliance	1.8433	1.952
Iterations	32	56

After optimizing the structure with ANSYS based OC approach method the optimized shape is obtained after 32 iteration which is given in the following figure 2(a) and figure 2(b) shows the optimized structure obtained by Wang et al. [3].



(a)



(b)

Figure 2. Optimized structure of MBB obtained by (a) ANSYS based OC method (b) Adaptive method

The above comparison shows that the ANSYS based OC method converges final compliance to 1.8433 N-mm after 32 iteration while Adaptive method converges it to 1.952 N-mm after 56 iteration. So it is observed that ANSYS gives results with better accuracy. The plot between compliance and iteration has been shown in the figure 3.

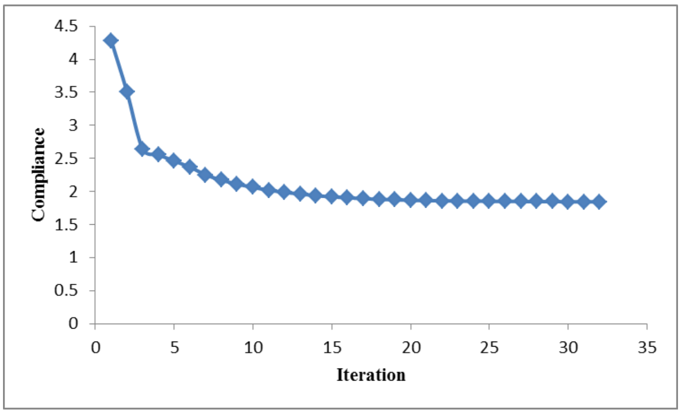


Figure 3. Variation of compliance with iteration

3.2. Model 2

In this case, an overhanging beam of dimensions in the ratio of 6:1 is considered. The beam model and loading condition is shown in the figure 4 below. The beam is optimized for minimum compliance. Young's modulus and Poisson's ratio used are 200 GPa and 0.29 respectively. The load applied is 20 KN at a distance 2 mm from the middle on both side. The mesh size used in this case is 150, 50 and volume use fraction is 50%. The final value of compliance and no. of iterations are given in the Table 2.1 below and the optimized structure is given in the figure 5.

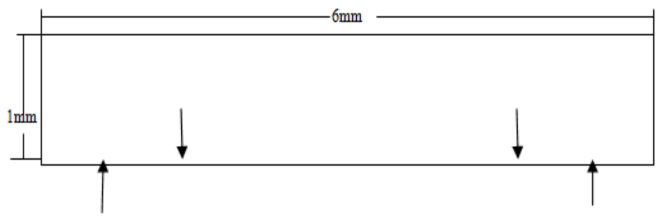
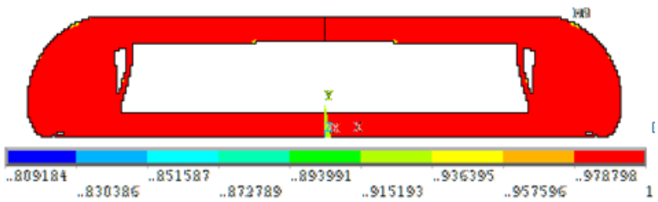


Figure 4. Structure with boundary and loading condition

(n_x, n_y, V_0)	(150, 50, 0.5)	
Method	**ANSYS based OC**	**OC**
Compliance	0.027694	0.0390
Iterations	27	84

Table 2.1: Comparison between ANSYS based OC and OC method



(a)

(b)

Figure 5. Optimized structure of overhanging beam obtained by (a) ANSYS based OC method (b) OC method

The above comparison shows that ANSYS based OC approach converges faster than OC method. It converges compliance to 0.027694 N-mm after 27 iterations while OC method converges the same to 0.0390 N-mm after 84 iterations. The variation of compliance with iterations has been shown in the figure 6.

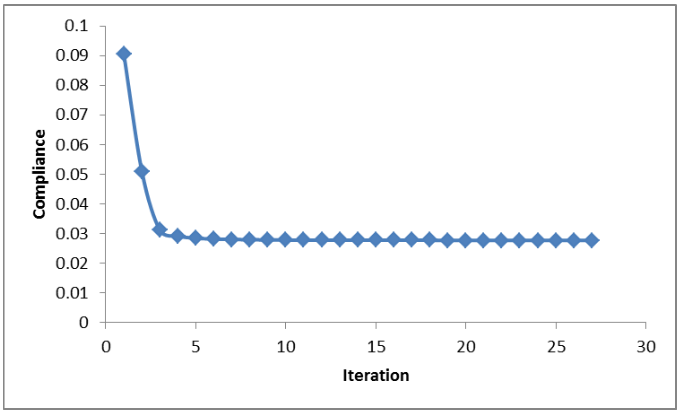


Figure 6. Variation of compliance with iteration

3.3. Model 3

A half ring with outer radius 10 mm and inner radius 3 mm is considered. The ring is fixed at one end as cantilever and two concentrated load of same magnitude in opposite direction is applied at other end of the ring. Young's modulus is 1000 and Poisson's ratio is 0.3. The load applied in opposite direction is 1 N. The model is shown in the given figure 7.

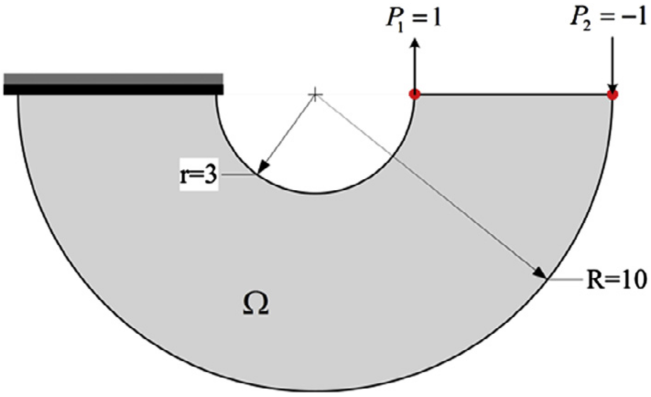
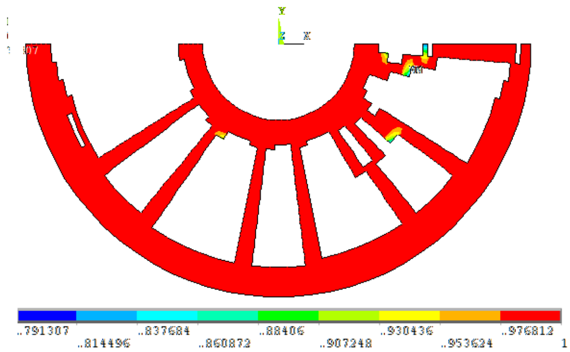


Figure 7. structure with load and boundary condition

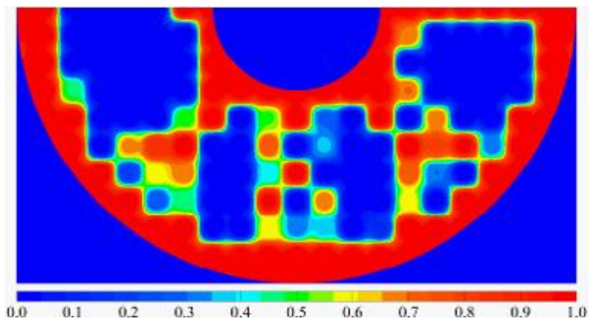
The final value of compliance and optimal topology obtained by ANSYS based OC and Adaptive method by taking two different mesh densities have shown in the Table 3.1.

Table 3.1: Comparison between OC and Adaptive method for model 2

(n_x, n_y, V_0)	Coarse mesh (21, 11, .5)		Fine mesh (121, 61, 0.5)	
Method	**ANSYS based OC**	**Adaptive method**	**ANSYS based OC**	**Adaptive method**
Compliance	0.0696	0.037	0.0704	0.078
Iterations	30	64	63	40

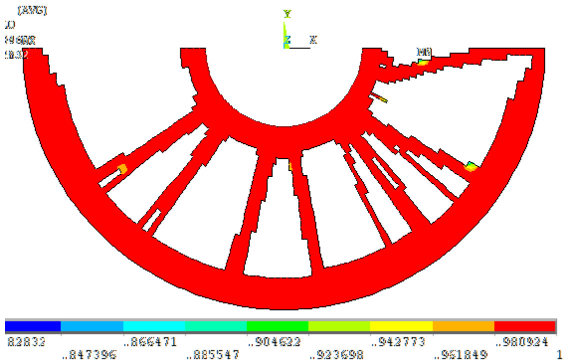


(a)

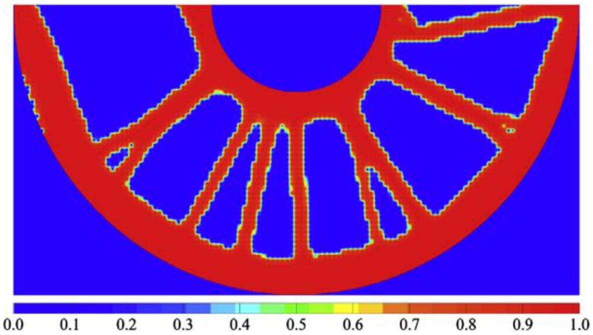


(b)

Figure 8. Optimized structure of half ring for mesh size 21, 11 obtained by (a) ANSYS based OC method (b) Adaptive method



(a)



(b)

Figure 9. Optimized structure of half ring for mesh size 121, 61 obtained by (a) ANSYS based OC method (b) Adaptive method

When the mesh size is 21, 11, the final value of compliance obtained by ANSYS based OC is 0.0696 N-mm after 30 iteration for volume usage fraction of 50% and compliance value obtained by Adaptive method is 0.037 N-mm after 64 iteration. The optimal shape obtained by both the methods is almost same as shown in the figure 8.

When mesh size changes to 121, 61 the compliance value obtained by ANSYS based OC is 0.0704 N-mm after 63 iteration for the same volume fraction of 50% and for Adaptive method compliance value is 0.078 N-mm after 40 iteration. The variation of compliance with iterations has been shown below.

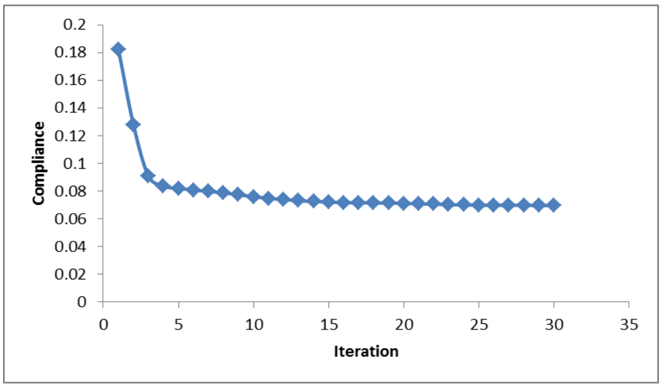


Figure 10. Variation of compliance with iteration for half ring for mesh size 21, 11

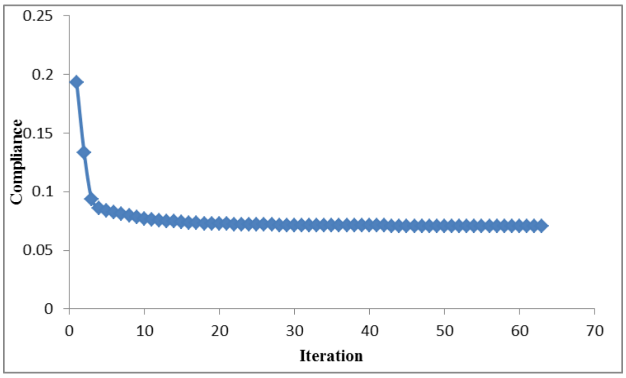


Figure 11. Variation of compliance with iteration for half ring for mesh size 121, 61

4. RESULT

In this paper, the optimal shape and change in compliance value has been studied for the given fraction of volume and different properties of material like, Young's modulus and Poisson's ratio. The objective of this study is to reduce the compliance and obtained an optimal shape for different model. The minimum compliance obtained at less iteration as compared to other methods which is our objective.

5. CONCLUSION

In this study, three models with different boundary conditions and different material properties are presented. All the three models are of same material which is linear elastic isotropic material. The models were optimized by using ANSYS based OC approach method and gives better results than other methods. In this work, a commercially available finite element solver ANSYS has been used to determine the optimal topology of the structures. This study conclude that the ANSYS based OC approach method is best suited for topology optimization. This study also concludes that the ANSYS based OC approach is better than the other methods because it gives quick and better results in very less iterations.

REFERENCES

[1] M. P. Bendsøe, and N. Kikuchi, (1988) "Generating optimal topologies in structural design using a homogenization method" Comput. Meth. Appl. Mech. Eng., vol: 71: 197-224.

[2] Suzuki, K. and Kikuchi, N. (1991). A homogenization method for shape and topology optimization. Comput. Meth. Appl. Mech. Eng. 93: 291-318

[3] Michael Yu Wang, Xiaoming Wang, Dongming Guo, (2003) " A level set method for structural topology

optimization" Comput. Methods Appl. Mech. Engrg.192:227-246

[4] J. Thomsen, (1992) "Topology optimization of structures composed of one or two materials" Struct. Multidisc. Optim., vol: 5: 108-115.

[5] Diaz, A. and Sigmund, O. (1995), "Checkerboard patterns in layout optimization" Struct. Optim.. Vol: 10: 40-45

[6] Zhen Luo , Li-Ping Chen , Jingzhou Yang , Yun-Qing Zhang ,Karim Abdel-Malek,(2006)," Fuzzy tolerance multilevel approach for structural topology optimization"Computers And Structures 84:127-140

[7] Zhan Kang, Yiqiang Wang, (2011), "Structural topology optimization based on non-local Shepard interpolation of density field".Comput.Methods Appl.Mech.Eng

[8] Metteto Bruggi, Macro Verani, (2011) "A fully adaptive topology optimization algorithm with goal-oriented error control" Comput. And Structures.

[9] Yiqiang Wang, Zhan Kang , Qizhi He,(2013)," An adaptive refinement approach for topology optimization based on separated density field description" Computers and Structures 117: 10–22

[10] Yiqiang Wang, Zhan Kang, Qizhi He,(2014) "Adaptive topology optimization with independent error control for separated displacement and density fields" Comput. And Structures.

